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Performance by Female Soldiers

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Effect of Heat and Chemical Protective Clothing on Sustained Mental  
Performance by Female Soldiers

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# Abstract

This study examined the effects of heat on sustained mental performance by sedentary female soldiers clad in chemical protective clothing. Seventeen women trained for 2 weeks on military tasks. Then, they performed the tasks for 7-h periods on 4 successive days [Days 1 and 3=21.1 C, 35%rh, battle dress uniform (BDU); Day 2=12.8 C, 35%rh, protective clothing over BDU; Day 4=32.8 C, 61%rh, protective clothing over BDU]. After 3 h in the heat in protective clothing, group performance began to deteriorate. Two persons had to be evacuated in the 3rd h of exposure, 3 in the 4th and 5 in the 5th. The remaining 7 showed no adverse effects on performance of any task. No differences were found between casualties and non-casualties in rectal temperature or water consumption. Performance of a majority of the group also was adversely affected by the protective clothing at 12.8 C, 35%rh. We conclude that the effects of heat and protective clothing on women are more severe than on men, but the reasons are not clear at this time. *Keywords:*

→ Climatic stress; military performance; group productivity; women

*Stress (Physiology). (SDW)*

Effect of Heat and Chemical Protective Clothing on Sustained  
Mental Performance by Female Soldiers

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The clothing system currently issued to military personnel for protection against chemical agents is relatively impermeable and substantially limits the dissipation of heat from within. The increased heat load has been shown to have an adverse effect on the performance of tasks requiring either physical (3,7,8,9) or mental (4,5,11,12) effort in both temperate and moderately hot environments.

With specific regard to so-called "mental" work, Pine and Kobrick (4,5) found that the performance of a group of highly trained male soldiers began to deteriorate markedly after four to five hours of sustained work at 32.8 C, 61%rh while wearing a chemical protective ensemble. By the end of seven hours, average group accuracy had decreased 17-23% from control conditions for investigator-paced tasks. Accuracy on self-paced tasks was not affected, but, with self-pacing, productivity declined to about 40% of control conditions.

All of the available information about sustained mental performance while wearing protective clothing in the heat appears to have been obtained from males. Yet, while women are not permitted in the combat arms, significant numbers of them are in support units which are likely to be involved in critical situations where chemical agents can be present.

There appears to be no basis upon which to predict differential cognitive performance of women relative to men under conditions of heat stress and protective clothing. Stephenson and Kolka (13) have noted that there have been few thermoregulatory differences shown between men and women in studies which

have been properly controlled for factors (e.g., physical fitness) which independently affect thermoregulation. While there is some evidence that both mental performance (2) and thermoregulation (13) vary with menstrual cycle, there appears to be no evidence linking mental performance with thermoregulation.

This study was undertaken to provide specific information about female performance of mental work in the heat while wearing chemical protective clothing. It is a replication of the research reported by Fine and Kobrick (4,5) with male soldiers. The focus of this first study of women was on performance rather than on thermoregulation.

As in Fine and Kobrick (4,5), three important criteria have been observed in the design of the research: (a) participants performed tasks that would be required of at least some troops during a chemical attack, (b) the tasks were overlearned, as they would be among highly trained troops, and (c) exposure to stress was at least for as long a time as the clothing is considered to provide protection.

The tasks in this study have been used effectively in previous research (4,5,6, and in unpublished research by Fine and Kobrick). They were modelled after components of tasks performed by members of Artillery Fire Direction Center (FDC) teams, forward observers and communications personnel, and are considered to be among the most important types of tasks that would be performed by troops under attack by chemical or any other weapons.

#### MATERIALS AND METHODS

Subjects: 18 female soldier volunteers, ages 20-34 (median=22), were studied. All were screened by a medical officer. Because of the need to wear a chemical mask in the study, all personnel were required to be able to read without glasses or to possess optical inserts for the mask. Participants were

briefed on the purposes, design and potential hazards of the study and signed voluntary consent forms. (The research conformed to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.)

Tasks: Four tasks were used as the major dependent variables. Each was designed to be consistent with controlled scientific investigation and to have credibility as a genuine military activity.

(1) "Codebook:" Receiving and decoding previously tape-recorded military communications, varying in length from five to eight words, which were transmitted as radio messages through headsets. The task required that each coded message be written as received, be decoded by referring to a simulated Army code book, and the translation written on an appropriate form.

(2) "Codewheel:" Receiving and decoding map grid coordinates which were transmitted as radio messages through headsets. The coded information had to be written as received, the appropriate one of three decoding devices ("code wheels") selected, the alphabetic information decoded into numeric format and the result written on a form.

(3) "Site:" Computation of "Site," a correction for the asymmetrical trajectory of an artillery round, involves the use of a special slide rule and the manipulation of numbers. (Computers now are used, but proficiency with hand tools is still required of some FDC members.) Tape-recorded information was transmitted over headsets in authentic military format. The information had to be written as received, addition and/or subtraction performed, the resulting data entered into the slide rule, the rule appropriately manipulated and answers read from it and written accurately on a form.

(4) Plotting targets on maps and determining ranges and deflections: All participants were given identical maps and identical lists of targets to plot. They were required to plot each target, using an artillery plotting scale,

mark the location of the target with a map pin, draw a circle around it and write the target number in the circle. They also were required to determine the range and deflection of the target from a designated battery (pre-plotted on the map), using an artillery protractor. Answers had to be written on a form and included the time of completion of the calculations for each target, enabling quantification of number of targets plotted per unit of time. A further complication was introduced by having a number of "No Fire Zones," delineated by sets of grid coordinates, listed on each person's report form. Awareness of these zones had to be indicated by noting on the form whether or not a specific target should be fired upon. The zones were changed after every ten targets to prevent their being memorized and to increase the need for alertness.

The Site computation task and the two decoding tasks herein are referred to as "radio" tasks. They were paced by the rate at which the radio messages were sent ("investigator-paced") and could not be controlled by the participants. The map plotting task at times was "investigator-paced" and at other times was "self-paced," i.e., each person had control of her own work rate (see below).

The subjects did not know which of the three radio tasks they had to perform until a specific message arrived. The messages were realistic in content and for and included a variety of speaking voices and transient background noises.

**Experimental Design and Procedure:** The subjects, in six-person groups, were scheduled to arrive at three-week intervals. Four groups were expected over approximately three months. Because of long-range scheduling problems and attrition of selected individuals prior to arrival, five groups, varying in size from three to four persons ( $N=18$ ) were obtained over a period of six

months. Each group completed its assignment prior to the arrival of the next one.

Each group was trained intensively for two weeks (exclusive of week-ends), 6-7 h/day, followed by one "experimental" week, the purpose of which was to evaluate performance in the heat while wearing chemical protective clothing. Both training and subsequent experimentation took place in environmentally-controlled facilities.

The clothing ensemble worn is known as the Mission Oriented Protective Posture (MOPP) system. It provides 4 levels of increasing chemical protection preparedness, ranging from minimum (MOPP-I) to maximum (MOPP-IV). MOPP-IV, which was used in this study, is total encapsulation, and includes a two-piece suit, worn completely closed over the battle dress uniform (BDU), along with boots, gloves, mask and hood.

Training for the radio tasks began with a simple written format and became increasingly complex, culminating in realistically simulated military communications. During training, several hundred radio messages were practiced, and hundreds of targets were plotted on maps. For all tasks, there was within-session feedback of correctness of responses and discussion of errors and their causes. Emphasis initially was placed on accuracy and later on speed, as accuracy goals were achieved. All subjects received constant individual attention.

During the first week of training, participants gradually were introduced to performing the tasks while wearing MOPP gloves and/or mask. During the second week, they performed the tasks daily in the morning with and in the afternoon without the MOPP-IV system at appropriate ambient temperatures (see below). By the beginning of the "experimental" week, everyone had performed all of the tasks in MOPP-IV for about 8 h, spread over 5 d.



The experimental week proceeded as follows: Monday-Two 1 h "refresher" sessions to re-establish pre-weekend performance levels on the tasks (21.1 C, 35%rh); Tuesday-"BDU-Control-1": 7 h at 21.1 C, 35%rh, battle dress uniform; Wednesday-"MOPP-Control": 7 h at 12.8 C, 35%rh, MOPP-IV worn over BDU; Thursday-"BDU-Control-2": same as Tuesday; Friday-"MOPP-Heat-Stress": 7 h at 32.8 C, 61%rh, MOPP-IV worn over BDU.

The MOPP-Control day was kept at 12.8 C so that it would be the physical equivalent of the 21.1 C BDU-Control condition for a 7-h exposure (calculated by J.R. Breckenridge, this Institute). This "matching" of environments was done to insure that performance in the MOPP-Control condition reflected only the effect of wearing the protective ensemble, and not the effect of additional heat due to encapsulation.

The radio tasks were presented as 1-h blocks of messages. Twenty-five messages were sent to each participant per h. Five of the messages were "irrelevant," i.e. types of messages to which the participants had been trained not to respond. Of the remaining messages, 6 were codewheel, 6 codebook and 8 computation of Site. The type of message and the interval between messages varied according to a pre-determined random pattern. Intervals ranged from approximately 30 s to over 2 min. There were no duplicate messages throughout the entire experiment.

Everyone received identical messages within each hour. However, the order varied from person to person, i.e., participant #1 received a sequence of messages from #1 to #25, and had the same sequence for all hours in which she received messages. Participant #2 received identical messages, but her sequence started with message #2 and ended with message #1. Participant #3 started with message #3 and ended with message #2 and so on. This procedure and the randomly variable intervals between messages insured that everyone was

working independently.

The radio messages were presented four times on each of the four experimental days as hours 1, 3, 5, and 7. The hours were matched in terms of the order and difficulty of the messages, e.g., if message #3 was a codebook message in hour #1, not only was it a codebook message in hours 3, 5 and 7, but it also contained the same number of words to decode.

While monitoring for radio messages, participants also plotted targets and determined ranges and deflections. However, radio messages were assigned highest priority. Map work was interrupted in order to respond to radio messages and to carry out the required performances. Map work was then resumed. Thus, during hours 1, 3, 5, and 7, everyone was continuously engaged in mental work.

During the 2nd, 4th and 6th hours, everyone worked continuously on map problems and were interrupted twice for brief individual testing of contrast sensitivity and eye-hand coordination (to be reported elsewhere). During these hours, everyone worked at her own pace on the map task for at least 30 minutes without interruption.

Each "one-hour" period included a 10-min rest period.

As a precaution on the MOPP-Heat-Stress day, rectal temperatures were monitored at 5-min intervals (more frequently if temperatures approached 39 C). Safety regulations required removal of personnel from the heat if rectal temperature reached 39.5 C. Water was kept readily available, drinking was encouraged and consumption was monitored to assure adequate hydration. Drinking while wearing the MOPP mask was accomplished by means of a rubber tube connecting mask with canteen. No food or beverages, other than water, were consumed during any of the experimental sessions. During training, smoking was permitted only during breaks. It was not permitted during the

experimental sessions. Access to a portable toilet was permitted during experimental sessions, but was discouraged. Very few persons availed themselves of the opportunity and those did so only during rest periods.

## RESULTS AND DISCUSSION

The data of one participant were excluded from analysis because of irregularities in behavior and performance.

The radio tasks were scored for accuracy using the criteria of Fine and Kobrick (4, Appendix 6). Each response was checked independently by two scorers. Their evaluations then were compared and discrepancies were resolved by discussion.

There were two types of errors; omission and commission. Omission involved missing part of an incoming message or performing an incomplete translation of it. Commission involved recording incoming information erroneously or erring in computing or translating it.

In the MOPP-Heat-Stress condition, 10 persons had to be evacuated for medical reasons; 2 in the third, 3 in the fourth and 5 in the fifth hours. All evacuees had either fainted, given indications that they were about to faint or were judged incapable of continuing by the medical officer and/or investigator. Criteria entering into the decision to evacuate included dizziness, incoherent responses to questions, feelings of total exhaustion, cessation of performance, or an expressed statement of desire to terminate. No one was removed because of hyperthermia. Average rectal temperature at time of removal for 10 persons was 38.2 C; only 1 person reached 39.0 C. Average temperature for the 7 women who were not evacuated was 38.0 C for each of hours 5 and 7. No differences in water consumption were found between evacuees and those who remained for the entire exposure. Body weights were not obtained, so weight loss could not be ascertained.

Emphasis was on unit performance, hence, as in Fine and Kobrick (4,5), evacuees were given the maximum number of omission errors possible for the radio tasks and scored as having plotted no targets for the time period they missed. Group averages are reported for all tasks and reflect this method, which provides a more realistic assessment of unit performance than would the exclusion of data from evacuees. Essentially, this is a "worst case" analysis, heavy weight being placed on becoming a casualty, as it would be in a combat situation. This procedure has been discussed by others at various times ( see Fine and Kobrick; 6, page 121).

With respect to the overall performance of the group, it is important to note that the 7 women who were not evacuated showed no significant adverse effects of heat on the performance of any task.

Analyses of variance (ANOVA'S) were computed for each of the tasks, using the error scores of each subject, in order to determine the effects of experimental conditions, elapsed hours of work and their interactions on task performance. The results of these analyses are presented in the text below.

The number of errors made by each person on each radio task was converted to percent of total possible errors for that task. The percentages then were averaged for the group, and are the basis for the graphs used herein.

"Internal" comparisons, i.e., differences between elapsed hours of work within conditions or between conditions after a given number of hours of work, were made using the Least Significant Difference Test (1,10).

CODEBOOK: The results for the Codebook task are shown in Fig. 1 and represent errors of omission and commission combined.

INSERT FIGURE 1 ABOUT HERE

The ANOVA for the codebook task resulted in significant main effects for Conditions ( $F=40.31$ ;  $d.f.=3,256$ ;  $p<0.00001$ ) and Elapsed Hours of Work

( $F=11.93$ ;d.f.=3,256; $p<0.00001$ ) and a significant interaction between the two ( $F=7.51$ ;d.f.=9,256; $p<0.00001$ ).

There were no significant differences between the two EBU-Control conditions at any hour of testing, nor were there any differences between hours of testing within either of the EBU-Control conditions. This indicates that the group had reached a consistent level of performance which did not vary significantly over 7 h.

Despite approximately 8 h of training while wearing it, the protective clothing, by itself (MOPP-Control condition), appeared to cause a significant decrement in performance of the Codebook task; comparison of the MOPP-Control condition with each EBU-Control condition yielded significant decrements at all hours of comparison. This result is similar to, but somewhat stronger than, that obtained by Pine and Kobrick (4,5) with males. Average group decrements ranged from 25% to nearly 38% over the 7-h period.

No clear-out effects of heat were seen until the fifth hour. Then, highly significant average decrements (57%) occurred, reaching 70% after 7 h. (It should be recalled here that the scoring system emphasized unit performance. Consequently, the large decrements in the fifth and seventh hours were due to the evacuation of many participants as heat casualties.)

CODEWHEEL: The results for the Codewheel task are shown in Fig. 2. For total errors (errors of omission plus commission), an ANOVA yielded a significant main effect for Conditions ( $F=40.76$ ;d.f.=3,256; $p<0.00001$ ) and Elapsed Hours of Work ( $F=8.41$ ;d.f.=3,256; $p<0.00001$ ) and a significant interaction between the two ( $F=7.87$ ;d.f.=9,256; $p<0.00001$ ).

INSERT FIGURE 2 ABOUT HERE

As with the Codebook task, performance in the EBU-Control conditions showed remarkable consistency and stability over the 7-h period; no

significant differences were observed between the two conditions at any hour or between hours in either condition.

Performance in the MOPP-Control condition showed a significant decrement (when compared with both EBU-Control conditions) in the first and third hours.

In the MOPP-Heat-Stress condition, the group showed no adverse effect of heat in the first hour. In the third hour, however, performance was significantly poorer than in either EBU-Control condition, but did not differ from MOPP-Control. Thus, as was the case with the Codebook task, for the first three hours, the decrement in performance appears to be attributable to the protective suit per se and not to a suit-heat interaction. The effects of heat became evident by the fifth hour, however, and, by the end of the seventh hour, average group error had reached 68.6%, obviously attributable to the evacuation of personnel.

COMPUTATION OF SITE: This was the only radio task in which the content was presented twice, due to the relative difficulty of the material. The effect of the message repetition is evident in the lower error rates (Fig.3).

#### INSERT FIGURE 3 ABOUT HERE

ANOVA of total (omission plus commission) error scores resulted in significant effects for Conditions ( $F=45.12; d.f.=3,256; p<0.00001$ ) and Elapsed Hours of Work ( $F=9.99; d.f.=3,256; p<0.00001$ ) and a significant Conditions by Hours interaction ( $F=10.23; d.f.=9,256; p<0.00001$ ).

The two EBU-Control conditions were exceptionally stable over time; EBU-Control-1 varied less than 3% from hour to hour over the 7 h and EBU-Control-2 varied no more than 1.3%. The two conditions also were remarkably similar to one another; the largest difference between them was observed at hours 1 and 3 and was only 1.5%.

The significant decrement in performance in the MOPP-Control condition

which was found with the Codebook and Codewheel tasks was not apparent here.

The MOPP-Heat-Stress condition did not differ from the MOPP-Control condition in the first or third hour, but in the fifth hour a dramatic increase in error rate to 54.1% occurred, attributable to the large number of evacuees. The average group error increased to 62% by the seventh hour.

MAP PLOTTING: The results of this task are separated into two categories: performance concurrent with radio message reception (hours 1, 3, 5, 7; "investigator-paced"), and performance without that interference (hours 2, 4, 6; "self-paced").

NUMBER OF TARGETS PLOTTED, HOURS 1, 3, 5, 7: The average number of targets plotted by the group by Conditions and Elapsed Hours of Work are shown in Fig. 4. ANOVA resulted in significant main effects for Conditions ( $F=59.5$ ; d.f.=3,256;  $p<0.00001$ ) and for Elapsed Hours of Work ( $F=3.98$ ; d.f.=3,256;  $p<0.01$ ). There was a tendency for more targets to be plotted in BDU-Control-2 than in BDU-Control-1 in hours 1 and 3; the difference is significant only for the third hour. This is identical to what was found with males by Pine and Kobrick (4,5). Performance in each of the two BDU-Control conditions was very consistent, testifying to the efficacy of the training.

#### INSERT FIGURE 4 ABOUT HERE

While accuracy was not affected, significantly fewer targets were plotted in the MOPP conditions than in either of the BDU-Control conditions. In the MOPP-Control condition, simply wearing the protective suit, without the added stress of heat, apparently interfered with performance as it had with the Codebook and Codewheel tasks. Output, while lower, nevertheless was very consistent from hour to hour (9.65, 8.94, 8.94 and 8.59 average targets plotted per person per hour for hours 1, 3, 5, and 7 respectively).

Performance in the MOPP-Control and MOPP-Heat-Stress conditions did not differ in hours 1 and 3, but by hour 5, as casualties started to occur, large and significant decrements in productivity (but not accuracy), due to heat, became apparent, increasing in the seventh hour.

NUMBER OF TARGETS PLOTTED, HOURS 2, 4 and 6: The results for hours 2, 4 and 6 are shown in Fig. 5. ANOVA resulted in a highly significant Conditions effect ( $F=36.71$ ;  $d.f.=3,192$ ;  $p<0.00001$ ) and a significant effect for Elapsed Hours of Work ( $F=3.78$ ;  $d.f.=2,192$ ;  $p<0.02$ ). As a group, participants performed approximately the same in each of the two BDU-Control conditions; the average number of plots per person per h ranged from 21.76 to 25.47, a very tight envelope.

#### INSERT FIGURE 5 ABOUT HERE

Performance in the MOPP-Control condition was significantly poorer than in either BDU-Control condition at each of hours 2, 4 and 6. Average scores for hours 2, 4 and 6 were not significantly different from one another.

Productivity in the MOPP-Heat-Stress condition was significantly less than in either BDU-Control condition at each of hours 2, 4 and 6. Productivity in the heat did not differ from MOPP-Control at hour 2, but declined rapidly and significantly at hour 4 and even further at hour 6, as the evacuation of stressed persons from the chamber proceeded..

RANGE, DEFLECTION AND PLOTTING ERRORS: As was the case in the Pine and Kobrick study (4,5), the training was so effective that very few errors were made in plotting targets or determining range and deflection. Range errors averaged .22 per h per participant over the entire study. Deflection errors averaged .41 per h and plotting errors averaged .78 per h. Because of the low incidence of errors, statistical analyses were not undertaken.

Pine and Kobrick (4,5) found that the combination of heat and protective



clothing led to a progressive deterioration (increased errors or decreased productivity) of the performance of male soldiers starting after three to four hours of sustained work. In their study, 18 of 20 persons were able to complete the seven-hour scenario. In the present study, degradation of the women's performance started at about the same time as the men's, but progressed much more rapidly. Significant numbers of women dropped out along the way, so that only 7 of 17 women survived the heat exposure. Since most of the women who had to be evacuated were performing quite well up until the time of evacuation, it is probably more appropriate in this study to refer to women's ability to sustain performance, rather than to the effect of the environmental stress on their mental performance.

The critical question is why males were able to "go all the way," albeit with some deterioration in mental performance, while most females more rapidly reached their limit of endurance, but showed relatively little deterioration in performance prior to reaching that limit?

One explanation may lie in the observation by Fine and Kobrick (4,5) that many of their male participants had sweated through at least part of the protective clothing in the heat. This was not found to be true of the women in this study, and is consistent with other information (13) which indicates that females sweat less than males at a given temperature. While differences in rectal temperatures were not found between male and female groups, it is possible that the differential survival rates between genders, at least in part, may have been due to increased evaporative cooling of many of the males, because of wet clothing, even with minimal wind (2.5 mph). Information is not available for a more detailed analysis of the thermal state of the subjects in either study.

Another explanation for the gender differences may lie in the observation

that the women complained much more frequently of upper body fatigue when wearing the protective clothing. This may be due to differences in physical fitness and/or to the fact that the women generally were smaller than the men and, consequently, were bearing proportionately more weight on the upper body, particularly as regards mask and hood, making the tasks more physically demanding to perform.

The poorer performance of both males and females in the MOPP-Control condition as compared to the two EDU-Controls also is difficult to explain. First of all, it is not likely that the poorer performance was caused by factors such as impeded manual dexterity due to wearing gloves or to impaired vision because of the mask (11). Everyone had trained about 8 h with mask and/or gloves prior to the MOPP-Control session and no difficulties in writing or manipulating the "tools" had been observed. Furthermore, the increase in errors in the MOPP-Control condition was primarily due to increases in errors of omission...to not receiving messages properly, for example, rather than to errors of commission, i.e., faulty writing or tool manipulation.

It is possible that despite performing in MOPP-IV during the training weeks, the anticipation of wearing the protective suit in the more realistic situation of the experimental week, in a climatic chamber, with the knowledge that 7 h of endurance was expected, aroused some anxiety and imposed its own stress on the subjects. If so, this additional stress took a greater toll of the females; male performance in MOPP-Control always approached EDU-Control levels by the seventh hour, whereas females, as a group, did not show this recovery.

It is informative to note that for all tasks, for both genders, performance in MOPP-IV on Day 4 (MOPP-Heat-Stress) began at precisely the same mean level that each group had reached at the end of 7 h on Day 2 in MOPP-IV

(MOPP-Control). This gives credence to the concept of there being an adaptation period in wearing the MOPP gear; it takes a while to get used to it. The adaptation, apparently, was more difficult, in general, for women than for men. This rationale is weakened somewhat by the fact that performance on the Site task was not significantly affected in the MOPP-Control condition. Since this was the only radio task in which messages were repeated, decrements in the other radio tasks in the MOPP-Control condition may have been a function of a single presentation of the messages. However, the fact that performance on the map plotting task, which was not dependent on message repetition, also deteriorated in the MOPP-Control condition argues against this latter interpretation.

CONCLUSIONS: If these results can be generalized, very serious impairments in the ability to sustain performance of cognitive tasks may occur among female personnel wearing chemical protective clothing in the heat; the "unit" represented by the 17 enlisted women in this study was decimated by more than 50% casualties prior to six hours of heat exposure. Additional research is needed to determine whether the gender differences observed between this study and a previous one with male subjects reflect basic physical, physiological or psychological differences or reside in transient factors particular to the samples involved, such as differences in physical fitness, size or experience.

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Special thanks to the women who participated in the project. Their depth of commitment to sustained mental work is evidenced by the control values obtained in the study.

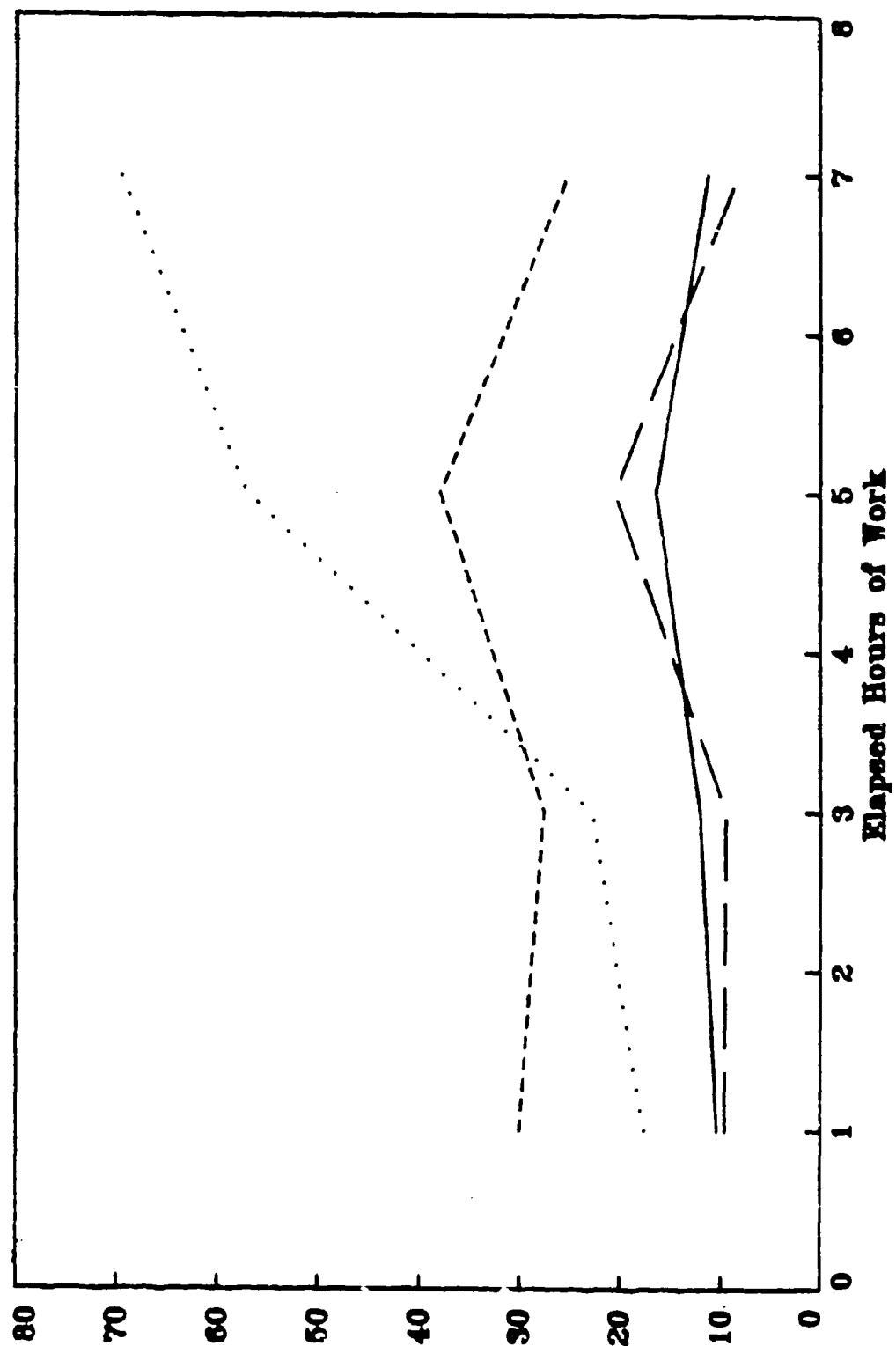


Fig.1. Codebook task total errors (commission + omission) as group mean percent with  $N=17$  (except in heat where  $N$  gradually decreased, see text). In each series of 4 d, there were two control sessions wearing the battle dress uniform (BDU), one control session wearing the MOPP-IV, and one heat-stress session wearing the MOPP-IV. The BDU control sessions were at 21.1 C; the MOPP control session was at 12.8 C (judged the equivalent of 21.1 C) and the MOPP heat-stress session was at 32.8 C. Task was performed during hours 1, 3, 5, and 7 only. BDU-Control-1=solid line; MOPP-Control=short-dashed line; BDU-Control-2=long-dashed line; MOPP-Heat-Stress=dotted line.



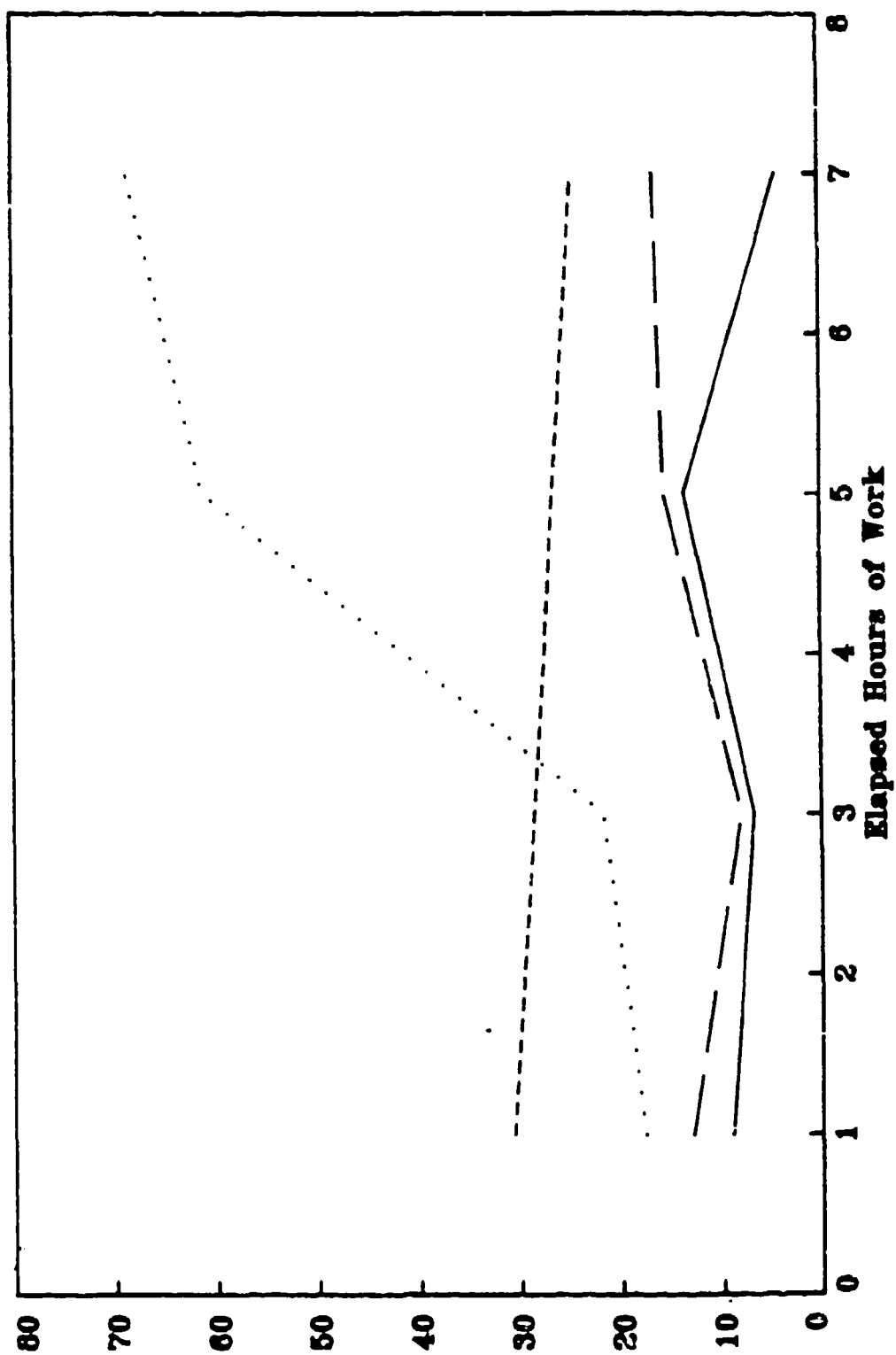


Fig. 2. Codewheel task total errors (commission + omission) as group mean percent with  $N=17$  (except in heat where  $N$  gradually decreased, see text). In each series of 4 d, there were two control sessions wearing the battle dress uniform (BDU), one control session wearing the MOPP-IV, and one heat-stress session wearing the MOPP-IV. The BDU control sessions were at 21.1 C; the MOPP control session was at 12.8 C (judged the equivalent of 21.1 C), and the MOPP heat-stress session was at 32.8 C. Task was performed during hours 1, 3, 5, and 7 only. BDU-Control-1=solid line; MOPP-Control=short-dashed line; BDU-Control-2=long-dashed line; MOPP-Heat-Stress=dotted line.

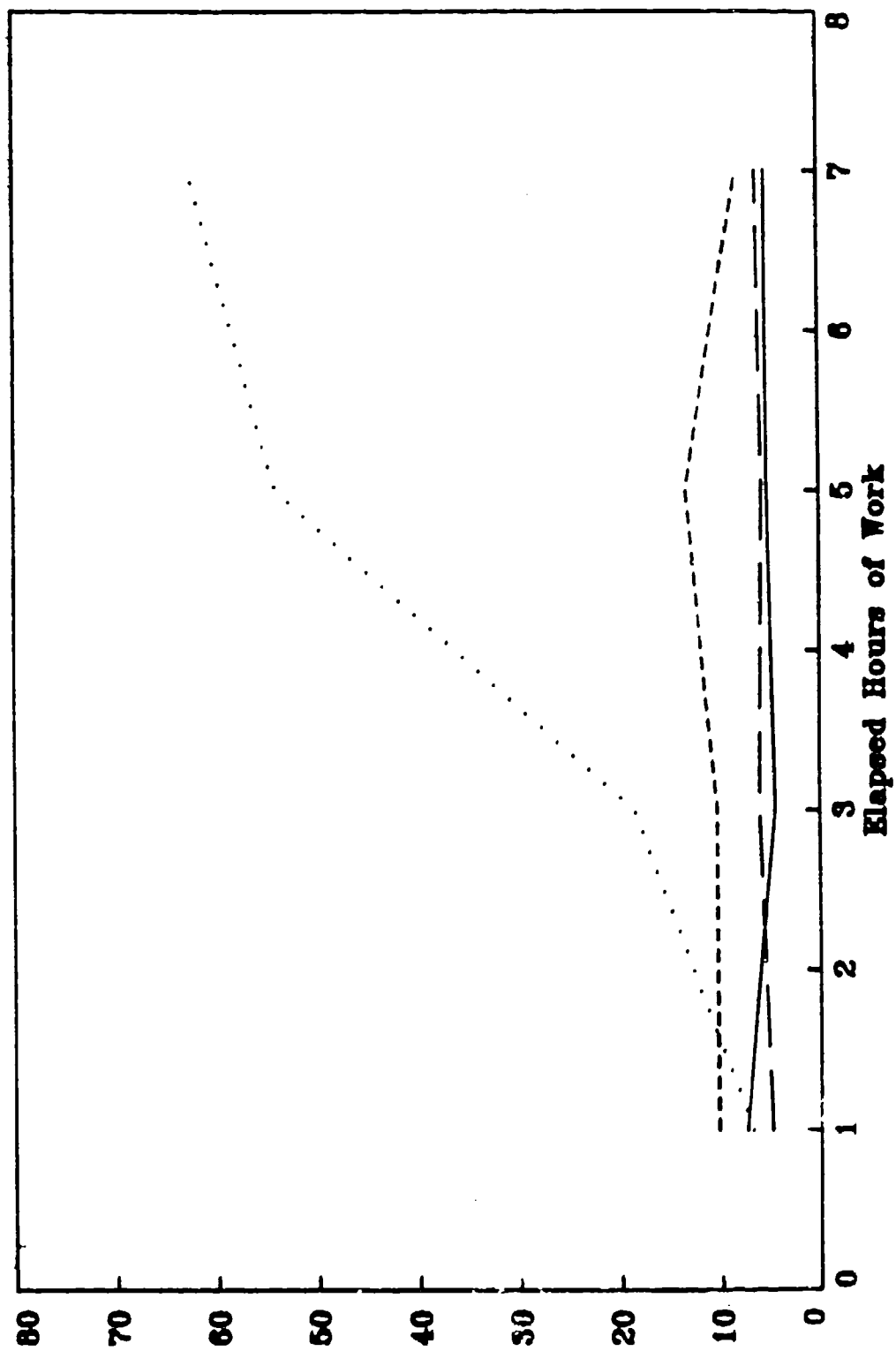


Fig. 3. Site computation task total errors (commission + omission) as group mean percent with  $N=17$  (except in heat where  $N$  gradually decreased, see text). In each series of 4 d, there were two control sessions wearing the battle dress uniform (BDU), one control session wearing the MOPP-IV, and one heat-stress session wearing the MOPP-IV. The BDU control sessions were at 21.1 C; the MOPP control session was at 12.8 C (judged the equivalent of 21.1 C), and the MOPP heat-stress session was at 32.8 C. Task was performed during hours 1, 3, 5, and 7 only. BDU-Control-1=solid line; MOPP-Control=short-dashed line; BDU-Control-2=long-dashed line; MOPP-Heat-Stress=dotted line.

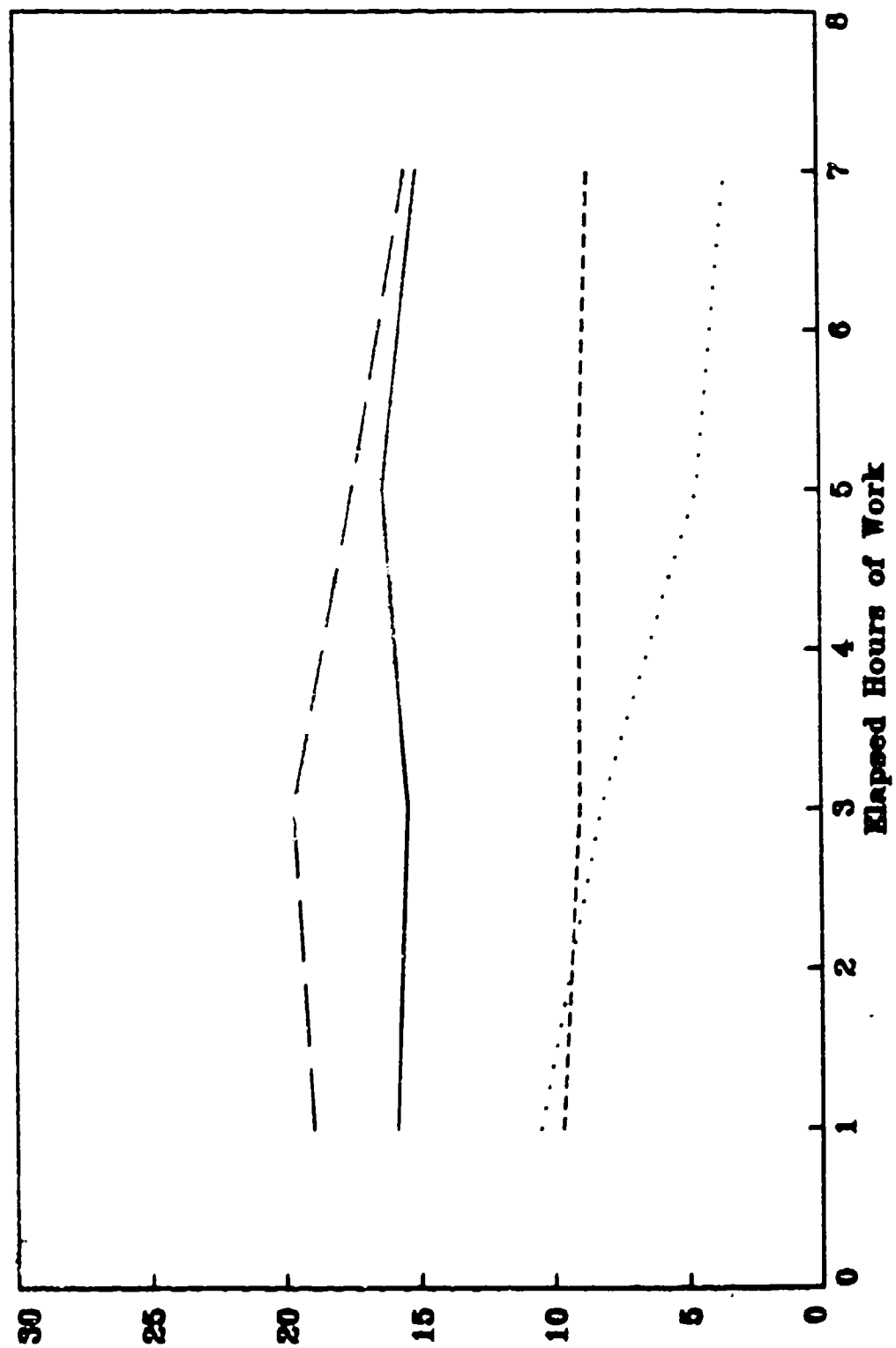


Fig. 4. Target plotting concurrent with radio messages as the number of targets plotted with  $N=17$  (except in heat where  $N$  gradually decreased, see text). In each series of 4 d, there were two control sessions wearing the battle dress uniform (BDU), one control session wearing the MOPP-IV, and one heat-stress session wearing the MOPP-IV. The BDU control sessions were at 21.1 C; the MOPP control session was at 12.8 C (judged the equivalent of 21.1 C), and the MOPP heat-stress session was at 32.8 C. Results depicted here are for hours 1, 3, 5, and 7 only. BDU-Control-1=solid line; MOPP-Control=short-dashed line; BDU-Control-2=long-dashed line; MOPP-Heat-Stress=dotted line.

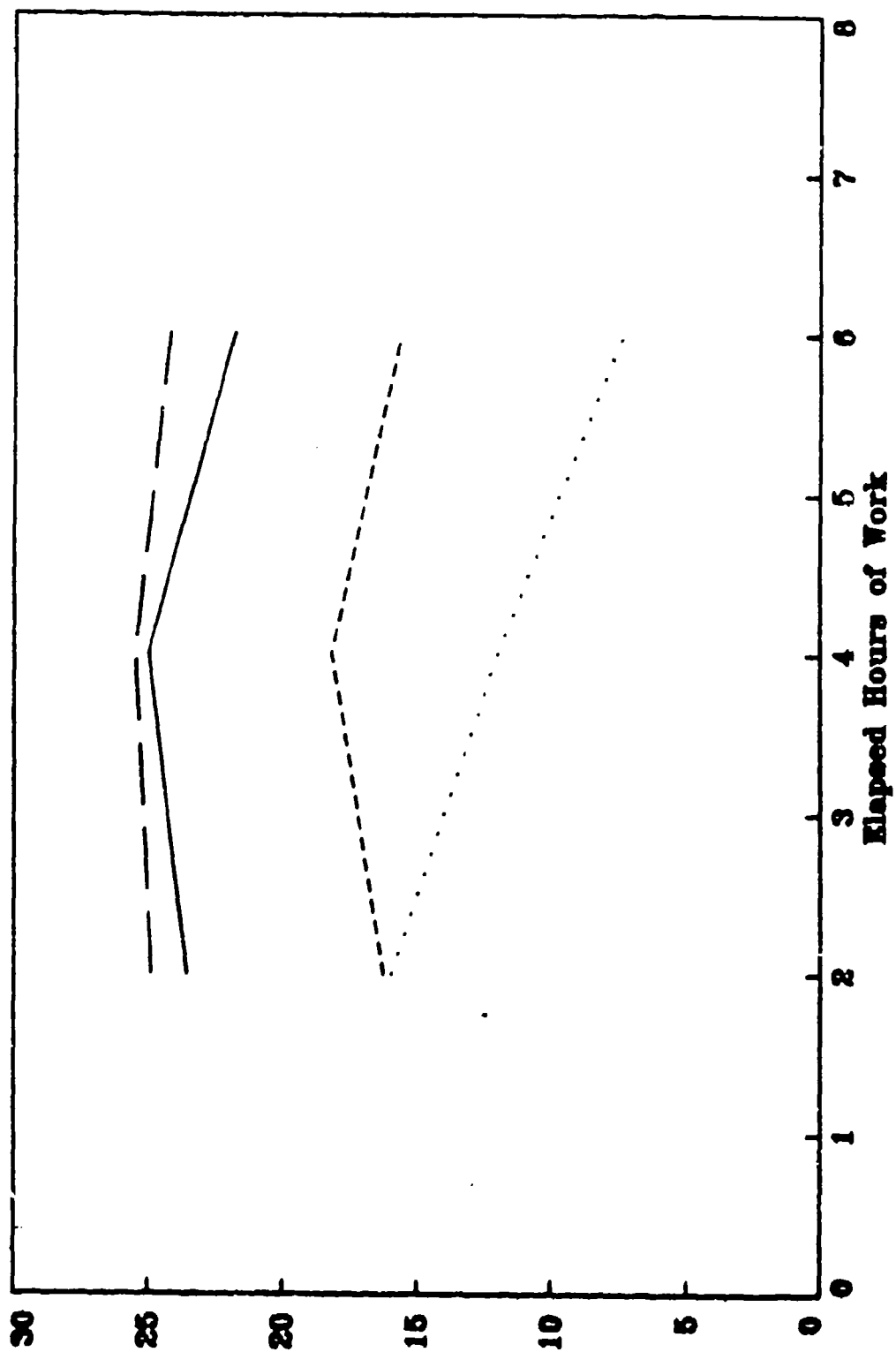


Fig. 5. Target plotting as the number of targets plotted with  $N=17$  (except in heat where  $N$  gradually decreased, see text). In each series of 4 d, there were two control sessions wearing the battle dress uniform (EDU), one control session wearing the MOPP-IV, and one heat-stress session wearing the MOPP-IV. The EDU control sessions were at 21.1 C; the MOPP control session was at 12.8 C (judged the equivalent of 21.1 C), and the MOPP heat-stress session was at 32.8 C. Results depicted here are for hours 2, 4, and 6 only. EDU-Control-1=solid line; MOPP-Control=short-dashed line; EDU-Control-2=long-dashed line; MOPP-Heat-Stress=dotted line.